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Technical Solution for Mitigating Radio-Frequency (RF) Interference to Air Traffic Control Communications

by Robert L. Atkinson

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14. ABSTRACT
This effort focuses on the unintentional disruption to air traffic control communications during Continuous Wave Immersion (CWI) testing on Satellite Communications (SATCOM) terminals in mid-November 2012; the source of the interference was identified as the fiber-optic data system being used by the U.S. Army Research Laboratory (ARL) team. Under “stand-by” conditions, a radio frequency (RF) system could generate and amplify broadband white noise. This broadband radiation interfered with communications between the air control tower and aircraft. The fiber-optic data systems in use by ARL possess the high technical qualities needed for the CWI measurements. Further, such systems are used throughout the Government and by its contractors in various testing configurations. Because of this, a technical “fix” (or fixes) was desirable to eliminate any future, similar occurrences. This report identifies the initial details that led to this effort, as well as the process pursued by ARL to technically resolve the white noise interference problem. The technical details underlying the problem are presented, as are the potential solutions that were considered. Finally, a technical solution, which represents the lowest-risk approach, was chosen and is described, in detail, within this report.

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Executive Summary

The effort reported here began with the unintentional disruption to air traffic control communications during Continuous Wave Immersion (CWI) testing on Satellite Communications (SATCOM) terminals in mid-November 2012. The testing ceased when the source of the interference had been identified as the fiber-optic data system being used by the U.S. Army Research Laboratory (ARL) team. Under "stand-by" conditions, a radio frequency (RF) system could generate and amplify broadband white noise. This broadband radiation interfered with communications between the air control tower and aircraft.

The fiber-optic data systems in use by ARL possess the high technical qualities needed for the CWI measurements. Further, such systems are used throughout the Government and by its contractors in various testing configurations. Because of this, a technical "fix" (or fixes) was desirable to eliminate any future, similar occurrences. This report identifies the initial details that led to this effort, as well as the process pursued by ARL to technically resolve the white noise interference problem.

The technical details underlying the problem are presented, as are the potential solutions that were considered. Finally, a technical solution, which represents the lowest-risk approach, was chosen and is described, in detail, within this report.

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1. Background

Continuous Wave Immersion (CWI) testing, which uses radio frequency (RF) emissions to assess operational readiness of Satellite Communications (SATCOM) terminals, was conducted at the Tennessee Air National Guard (TNANG) facility from 30 October 2012 to 15 November 2012. The TNANG facility is co-located with the Tyson McGhee Municipal Airport in Alcoa, TN.

From a technical perspective, the tests were, for the most part, successful. However, the efforts were not without incident. The testing ceased at approximately 15:20 on 15 November 2012. At that time, it was positively identified that some of the equipment in use by the U.S. Army Research Laboratory (ARL) team was, and likely had been, the source of sporadic disruptions in air traffic control communications. The disruptions occurred from 8–9 November 2012 and again from 14–15 November 2012.

This conclusion, as well as the decision to cease ARL's operations, came as a result of a concerted effort by members of various Governmental agencies to identify and characterize the source of the disruptions. When it became clear that the RF system in use could, at times, amplify broadband white noise, thereby causing interference between the air traffic control tower and aircraft communications, the testing was brought to a halt.[1]

At this point, it was agreed by all principals that testing would not continue until the situation, the equipment issues, the impact to the military Program, and all other factors had been evaluated. A meeting on these subjects was then held and, following the discussions, a follow-on teleconference between all concerned parties on the subject was scheduled for 10:00 on 16 November 2012. At the conclusion of the teleconference, the test equipment was returned to ARL's Adelphi Laboratory Center (ALC) and work began immediately to determine alternative solutions to mitigate the white noise problem.

[1] Memo for Chief, Power Components Branch, Subject: After Action Report – CWI Tests at TNANG, 15 November 2012.

2. Action Plan

Potential solutions that could be used by ARL to avoid further disruptions to air traffic control were identified and evaluated in the 19–30 November 2012 time-frame. Concurrent to these efforts, a Plan of Action (PAO) was identified and reported to the military sponsor, the Program Manager for Wideband Enterprise Systems (PM WESS).[2]

On 3 December 2012, the lowest-risk approach was identified and fabrication of the technical solution begun. In order to demonstrate the solution, a facsimile of the proposed test setup and solution was assembled in Building 500 for review by all interested parties. The demonstration dates were set for the period 12–13 December 2012.[3]

3. Technical Details–The Problem

Appendix C of MIL-STD-188-125-1 specifies the procedures for CWI testing. These procedures are used to validate the RF shields of some military facilities, such as the SATCOM terminals, to a particular variety of electro-magnetic threats. The typical CWI test measurement setup used by ARL is shown in figure 1.

[2] Memo for Chief, Power Components Branch, Subject: Plan of Action (POA) to Complete Continuous Wave Immersion (CWI) Testing at Site ‘T’, 26 November 2012.

[3] Memo for Record, Subject: Continuous Wave Immersion (CWI) Testing – Solutions Demonstration, 3 December 2012.

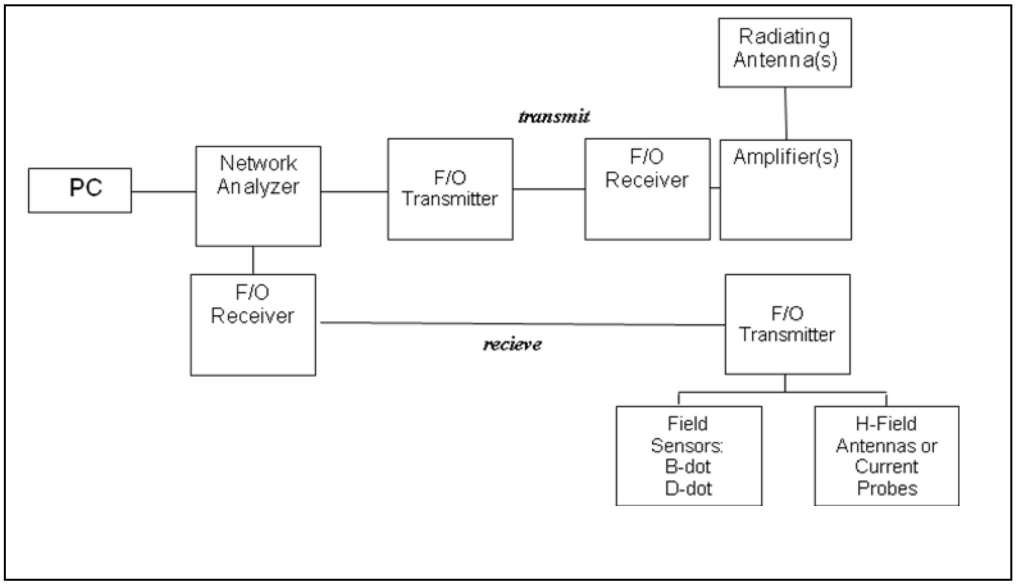

Figure 1. Functional CWI test equipment setup.

The fiber-optic data systems in use by ARL, which are shown on both the RF source transmit portion of the setup as well as the data receive portion of the setup, possess the high technical qualities needed for the CWI measurements. During the deliberations held in late November, it was determined that the interference problem was being created by the fiber-optic system on the transmit portion of the test setup. It was subsequently discovered that broadband RF noise can be emitted, under certain conditions, by the fiber-optic receiver. Such conditions can occur for a variety of reasons including: (1) lack of coherent signal input to the fiber-optic transmitter, (2) power to the fiber-optic receiver being turned off, and (3) loose or degraded fiber-optic cables that connect the fiber-optic transmitter to the fiber-optic receiver.

The source of the broadband noise is the automatic gain control (AGC) circuit that is within the fiber-optic receiver. When coherent signals are present at the input to the transmitter, the output of the AGC is at a minimum level, which is on the order of –10 dB. This is its normal operating state. However, when one of the three previously identified conditions arise, the AGC will increase its output as it searches for a coherent, incoming signal from the transmitter.

If no such signal exists, the AGC output state increases to its maximum, which is about 40 dB above normal. Since the output of the AGC is reflected directly at the output of the fiber-optic receiver and, if the RF amplifier is turned on, the result is to send the AGC output to the radiating antenna. When amplified and transmitted, this broadband noise would disrupt the air traffic control communications. Since such systems are used throughout the Government and by its contractors for various RF testing configurations, a technical “fix” (or fixes) would need to be devised to eliminate any future occurrences, if possible.

Typically, the network analyzer and fiber-optic transmitter are co-located. If a RF shielded room is available, both instruments would reside inside the shielded area. The fiber-optic receiver and amplifier are also co-located. More often than not, they reside outside of the shielded area and relatively close to the radiating antenna. As an example, figure 2 shows a typical setup configuration for the transmit portion of the test setup.

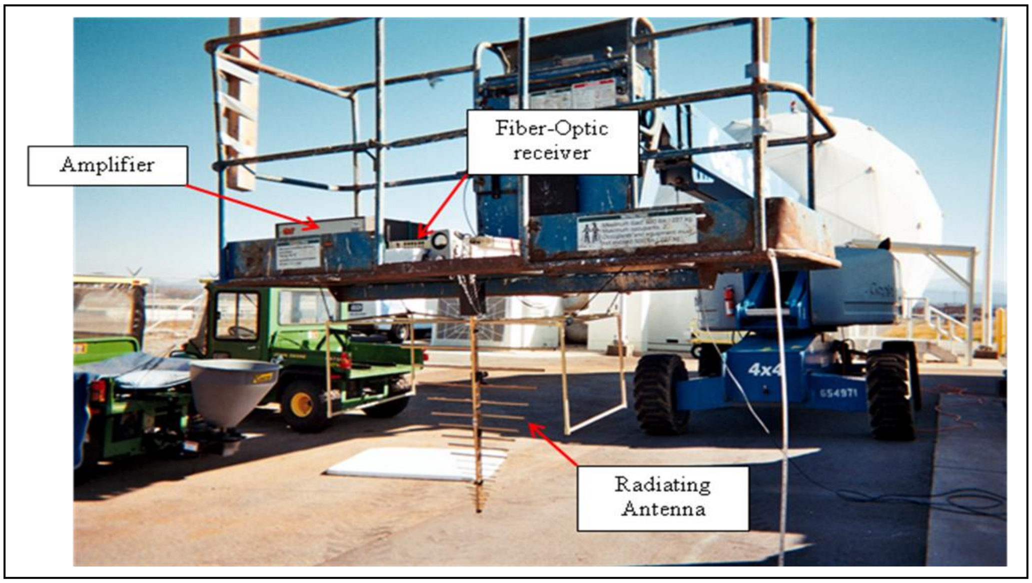

Figure 2. Fiber-optic receiver and amplifier in lift-bucket.

4. Potential Solutions

From the outset, every reasonable solution was considered. Some were administrative — simply changing the existing Standard Operating Procedure (SOP) used for the tests. Many were technical in nature. Others consisted of a combination of both administrative changes and technical solutions. All were evaluated with three conditions in mind. These were to accomplish the following: (1) reduce the risk of a re-occurrence, preferably to zero, (2) effect the change(s) in the shortest amount of time, and (3) incur the least expense to the Government.

Understandably, the initial deliberations all focused on changes to the SOP. These included the administrative (i.e., procedural) controls all ready in use. On 15 November 2012, it was discovered that the interference conditions were initiated by loosening and removing either of the two fiber-optic data lines on the rear of the fiber-optic transmitter, as shown in figure 3. Such was being repeatedly performed during the tests in order to preserve the transmitter’s battery life or move the transmitter from one terminal to another.

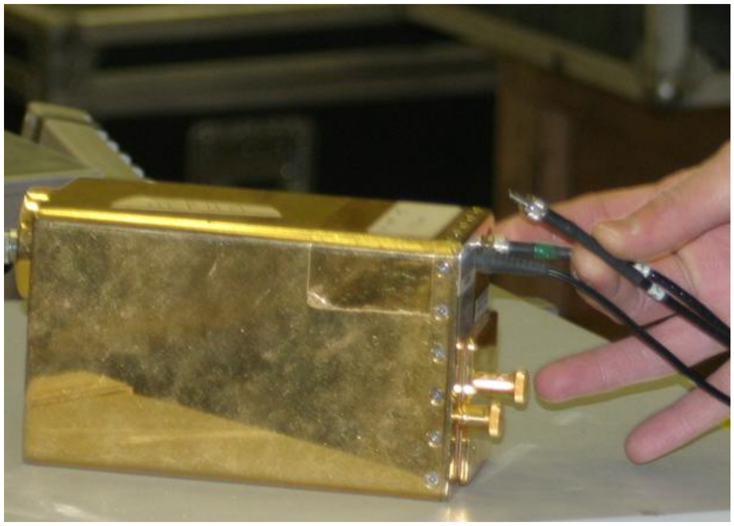

Figure 3. Transmitter with cable removed.

One solution, requiring only minor modifications to the existing SOP, would have been to simply disable the amplifier prior to removing a fiber-optic cable from the transmitter. Unfortunately, that process could not account for any unforeseen failures in fiber-optic data system during the normal test process, such as an accidently loosened or broken fiber-optic cable. Further, disabling the amplifier would have meant de-energizing the circuit that fed electrical power to the lift bucket. Just “pulling the plug” would have cut the power to the amplifier, as well as the fiber-optic receiver. When electrical power was restored by reinserting the plug, there could be no guarantee that all of the relays within the fiber-optic transmitter would successfully reset, thus causing a high-AGC condition. Finally, the solution does not account for human error. As a result, it was determined that merely updating the test process controls would yield an insufficient solution.

Another solution considered the inclusion of additional software controls to enable and disable all of the electronic components. Both the network analyzer and the fiber-optic data system are equipped for control by a general purpose interface bus (GPIB). Software control of both machines could be used to turn the fiber-optic transmitter on and off, as well as set the limits for the network analyzer’s operations. Although not controllable via GPIB, the amplifier could be controlled to a degree through the use of its serial port. In short, the amplifier output could be enabled only when the fiber-optic transmitter is “on” and the network analyzer is transmitting.

In order to implement that solution, three things would be needed: (1) a fiber-optic system for GPIB and serial port control signals, (2) a GPIB-Ethernet controller, and (3) the software solution. Of the three, the software needed for total control of all elements could be developed in-house. The fiber-optic system and GPIB controller could likely be procured for under $2K. Delivery of these components was expected to occur within 60 to 90 days. However, the development of the software represented the longest “lead item.” The minimum, useable set of coded instructions was expected to take approximately 3 man-months to develop and would incur costs, in labor, much greater than the electronic component costs. Regardless of the procurement and software development challenges, the solution could still not account for unforeseen failures in fiber-optic data system, broken cables, or the like.

Another potential solution considered the use of two coaxial switches, a directional coupler, and latching relays to control the amplifier output. The coaxial switches would be placed between the output of the fiber-optic receiver and the input to the amplifier. The latching relays and directional coupler, placed on the output of the amplifier, could serve to redirect any unintentional, broadband output from the radiating antenna to a non-radiating 50-ohm “load.”

A series of “bench tests” would be needed to test and finalize the initial design (figure 4). Estimated electronic component costs were on the same order of magnitude as the software solution. Although the minimum man-hour labor load was expected to be only about a month, the inability to quickly verify a “final” circuit design represented the highest risk.

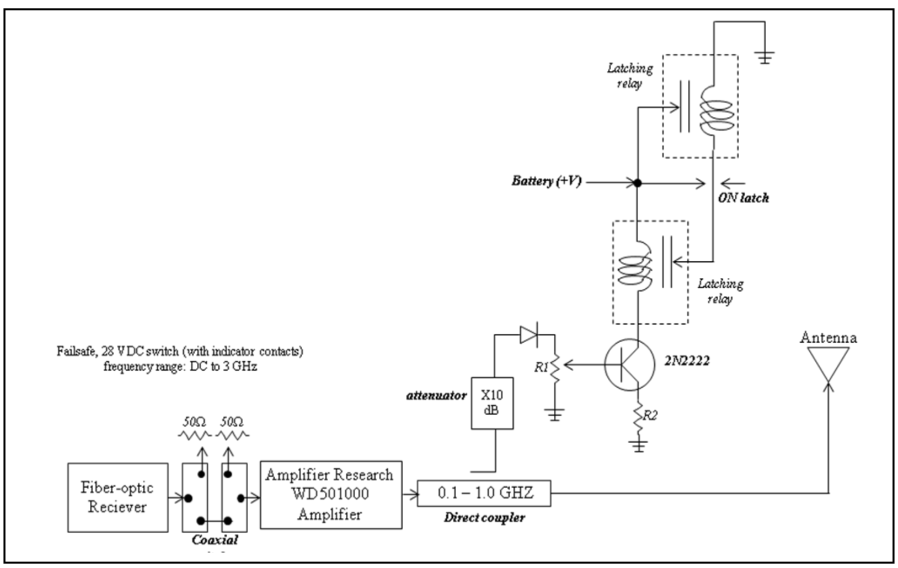

Figure 4. Partial solution–switches, relays, and couplers.

Use of a second fiber-optic system and latching relays to control the amplifier output were also considered. This potential solution considered the use of a second, fiber-optic data system, which monitored the level of “noise” output from the first fiber-optic receiver. If high-levels were detected, the amplifier output would be disabled, either at the input to the amplifier or by re-direction at the amplifier output.

Costs were estimated to be very similar to those of the previous solution. Electrical component costs were estimated to be about $2K. Reuse of other fiber-optic data systems in the ARL inventory would negate the need for additional procurement costs. Also, the minimum man-hour labor load for implementation was expected to be, again, only about a month. However, two significant disadvantages to this solution were (1) use of an additional fiber-optic data system in the test setup and (2) the inability to quickly verify a “final” circuit design. As with the earlier solution, this latter fact again represented the greatest risk to success.

Of all that was under consideration, two alternatives surfaced that appeared to possess the least amount of technical risk to a timely solution. One of these alternatives considered using the fiber-optic receiver’s internal circuitry to disable the output to the amplifier. The other alternative considered removing the AGC and related components of the fiber-optic receiver so that the emissions phenomenon could never occur.

Concerning this latter solution, if all of the fiber-optic receiver functions with the exception of the transmitter power controls were disabled, the need for an AGC would be removed. Without a functioning AGC, the broadband noise could not exist. In order to implement this, one of the existing fiber-optic data systems would have to be cannibalized, an expensive proposition. It was felt that such modifications to the fiber-optic receiver, so that only transmitter power was functioning, could not be performed “in-house” and would likely need to be contracted. However, manufacturer costs for the modifications, or the length of time needed to make the changes, were not immediately known.

A more practical solution arose from the other alternative, which was to use the fiber-optic receiver’s internal circuitry to disable the output to the amplifier. This concept introduced the advantage of disabling, in entirety, the amplifier.

By close-of-business 4 December 2012, the potential set of solutions was summarized in table 1. After a bit of introspection, however, it was determined that the most viable alternative would be to use the fiber-optic receiver’s internal circuitry to disable the amplifier. Further, the “trigger” mechanism for this action could be easily drawn from the internal circuitry of the fiber-optic receiver at minimal expense.

Table 1. Alternatives matrix.

	Potential Solution	Advantages	Dis-advantages
1	Use Low Signal LED of Fiber Optic Receiver to provide ON/OFF power to Amplifier	Electrical 110V power cut to Amplifier when Fiber Optic Transmitter connectivity is jeopardized	Fiber Optic Receiver "Re-set" status is unknown without further bench testing. Estimated costs: $250.00 for electrical components and ~ 4 days man-labor
2	Disable all Fiber Optic Receiver functions except transmitter power controls thereby removing AGC functioning in Receiver	AGC circuit is removed from the test set-up thus eliminating the "source" of broad-band "noise"	Modifications to the Fiber Optic Receiver cannot be performed "in-house" Contracted, manufacturer costs for the modifications are unknown.
3	Use two coaxial switches, a directional coupler, and latching relays to control the Amplifier output.	Unintentional broad-band output could be directed to a non-radiating "load"	Design cannot be finalized without further bench testing. Estimated costs: $1K - $1.5K for electrical components and ~ 2 - 3 man-weeks labor.
4	Use software controls to enable/disable all electronic components.	Amplifier output to radiating antenna enabled only when the fiber-optic transmitter is "on" and the Network Analyzer is transmitting.	Does not account for un-foreseen failures in Fiber-Optic Receiver system. Estimated costs: $1.5K - $2.0K low data-rate fiber-optic system for GPIB and ~ 3 man-month labor for software code.
5	Update test process controls to eliminate activities that would inadvertently enable elevated output from the AGC	Requires only minor modifications to the existing SOP.	Does not account for un-foreseen failures in Fiber-Optic Receiver system. Does not account for human error.
6	Use a second Fiber Optic System and latching relays to control Amplifier output.	Fiber Optic transmit system monitored and Amplifier output disabled when AGC "noise" detected.	Requires two, dedicated Fiber Optic systems. Estimated costs: ~ $1K for electrical components and ~ 2 - 3 man-weeks labor.

5. The Technical Solution

The technical solution described at the end of section 4 was fabricated and assembled, tested for validity, and used for the demonstration presented at ALC on 12–13 December 2012. Technical details for the solution follow in successive paragraphs. In general, the solution (figure 5) very closely resembles the typical CWI test measurement setup previously used, with two important modifications.

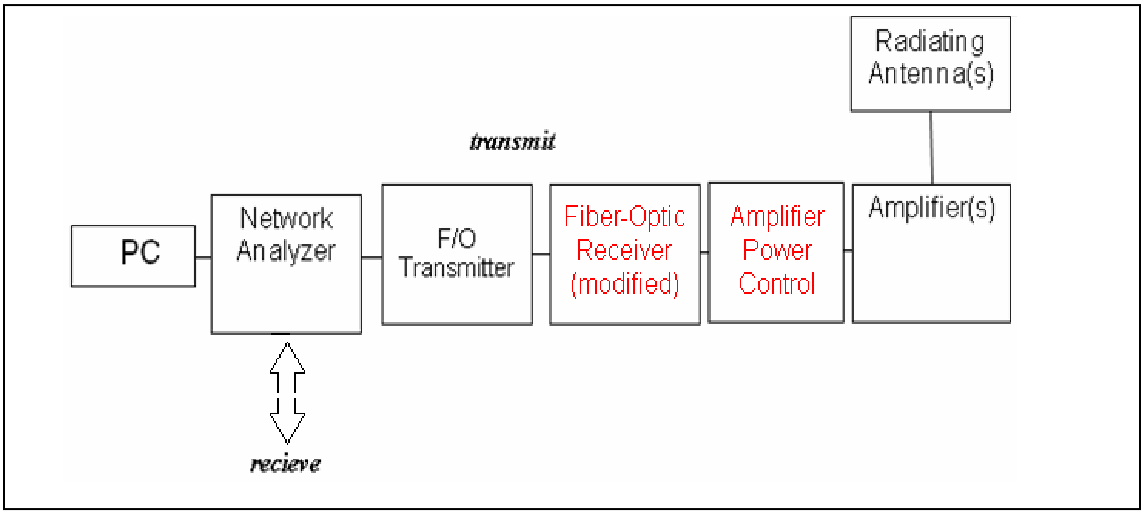

Figure 5. Modified CWI test setup.

First, the fiber-optic receiver was modified so that the status of the AGC circuit, which is represented by either a –8 or +4 VDC electrical signal, is made available as a hard-wired output. The –8 VDC is the electrical level realized when the AGC receives a coherent input signal. This is the “normal” operating state, wherein the output of the AGC is at its lowest levels, typically –100 dB. The +4 VDC is the electrical level realized when the AGC does not receive a coherent input signal. Without a coherent input signal, the AGC increases its output. This results in the broadband noise conditions. Either voltage level was made available at an output connector on the fiber-optic receiver. The output connector was mounted on the rear of the chassis (figure 6).

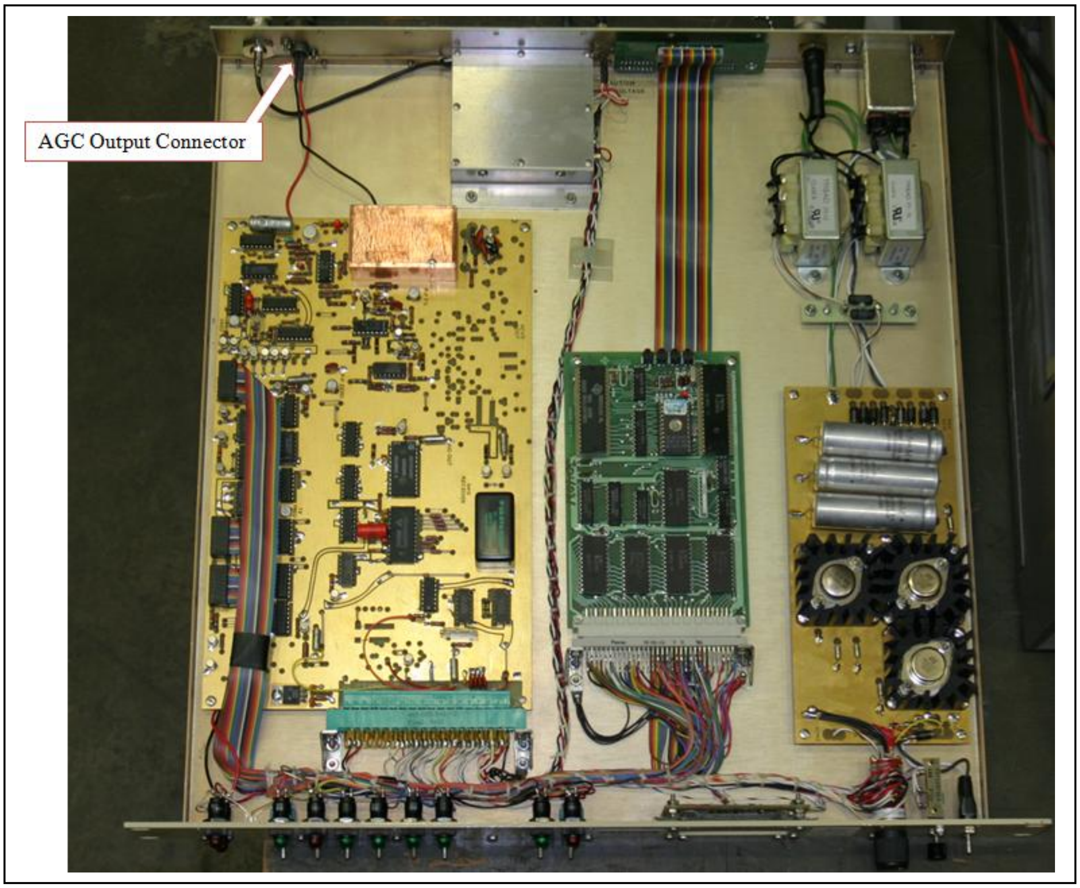

Figure 6. Fiber-optic receiver, modified.

Second, an electrical power supply module for the amplifier was fabricated (figure 7). Electrical +110 VAC power to the amplifier, which is supplied by the module, is either enabled or disabled based upon the signals from the modified fiber-optic receiver's output connector. When the AGC circuit inside the fiber-optic receiver lacks coherent input signals, the +4 VDC signal is sensed by the power supply module which cuts electrical +110 VAC power to the amplifier. Electrical +110 VAC power to the amplifier can only be restored when the fiber-optic receiver and the AGC receives coherent input signals.

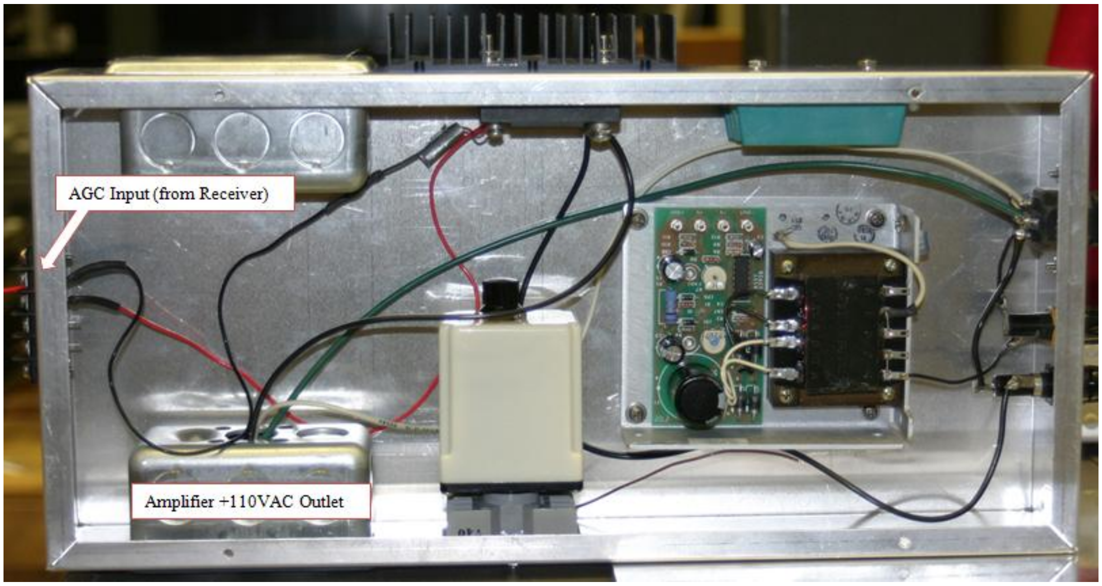

Figure 7. Electrical power supply (+110 VAC) module.

6. Operational Controls

Following the successful demonstration at ALC on 12 December 2012, discussions were held to identify the process that was to be used for follow-on testing at the TNANG facility. The previous testing established a thorough CWI data set for the SATCOM terminals for frequencies above 20 MHz. No further testing within that frequency range was necessary. However, the data set below 20 MHz were incomplete. As a result, additional RF tests within the range 100 KHz to about 20 MHz were recommended. As a result, tentative plans were made to perform the tests as soon as was reasonably possible.

Preparations for those tests included revisiting the test setup process, which was to be very similar in many ways as the original. As with the earlier tests, the network analyzer and fiber-optic transmitter are to be located within the RF shielded shelter. The test frequencies, which originate from the network analyzer, are passed through the terminal wall via the fiber-optic cables. Transmit power can be controlled by the network analyzer so that a power setting of about –6 dB equates to a radiated power output from the amplifier that does not exceed 10 W.

As before, the fiber-optic receiver and amplifier are positioned outside of the RF shelter, on the lift bucket (see figure 2). This time, the equipment compliment in the bucket will include the modified receiver and the electrical power supply (+110 VAC) module for the amplifier. The equipment configuration is shown in figure 8. (Not shown in the figure are the two inverted “V” antennas used to radiate the test signals). Electrical power for the equipment will again be drawn from the lift bucket.

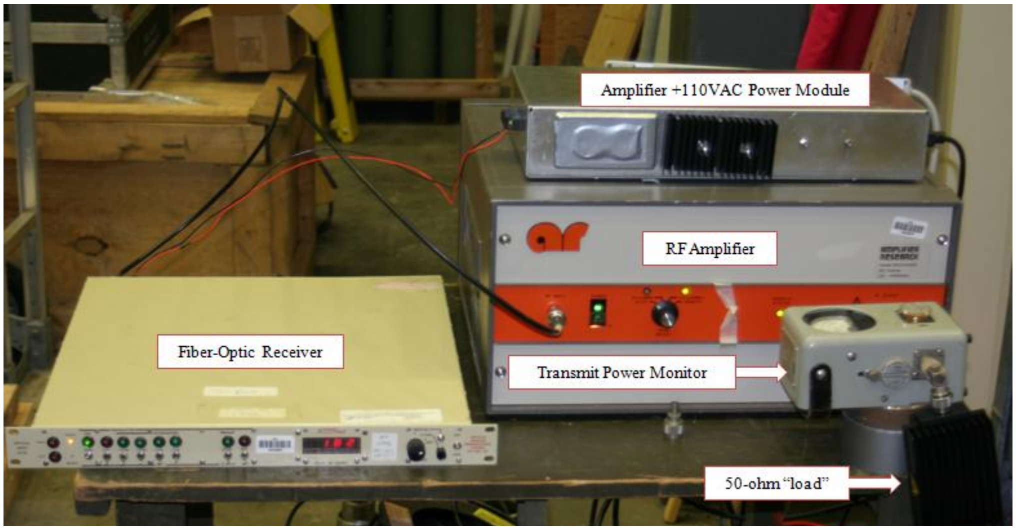

Figure 8. Transmit configuration (new).

Prior to elevating the bucket, there are two significant activities that will occur. First, the components within the bucket will be energized and all elements inspected for proper operation. Tests will be performed to ensure that the loss of coherent input signals to the fiber-optic receiver will result in the electrical power being removed from the amplifier. When the equipment operation has been verified, air traffic control tower personnel will be contacted for the purpose of informing them that testing will begin in the near future.

Provided that there are no objections or other mitigating circumstances, the ARL team will de-energize electrical power to the lift bucket and transmitting equipment and begin to elevate the lift. At approximately 10–12 ft above the terminals, the 50-ohm "load" on the amplifier output will be disconnected and a balun and the two inverted "V" antennas will be connected in its place. When this has been accomplished, the lift bucket will continue to be elevated until a height of about 50 ft has been achieved. Once fully elevated, air traffic control tower personnel will again be contacted. A direct telephone line between the test team and the control tower will be maintained as electrical power is restored to the lift bucket and the testing begins.

Since planned test frequencies (about 100 KHz to about 20 MHz) fall well below the range of frequencies typically used at the Tyson McGhee Municipal Airport for air traffic communications (about 118 to about 361 MHz), it is very unlikely that the testing will cause interference. However, should any interference to air traffic communications be experienced in the tower for any reason, electrical power to the lift bucket will be immediately cut and ARL's testing will cease. If such occurs, testing will not continue until the situation has been fully assessed and resolved.

7. Conclusions

The lowest-risk approach to eliminating the source of unwanted “broadband” RF interference that may result from the use of a fiber-optic data system has been identified. A working model of the solution was assembled and demonstrated at ARL’s ALC in mid-December 2012. Technical details of that solution, including background information, have been presented within the body of this text. Provided that permission is granted, the equipment identified will be used to complete the CWI testing effort later this fiscal quarter.

List of Symbols, Abbreviations, and Acronyms

AGC	automatic gain control
ALC	Adelphi Laboratory Center
ARL	U.S. Army Research Laboratory
CWI	Continuous Wave Immersion
GPIB	general purpose interface bus
PAO	Plan of Action
PM WESS	Program Manager for Wideband Enterprise Systems
RF	radio frequency
SATCOM	Satellite Communications
SOP	Standard Operating Procedure
TNANG	Tennessee Air National Guard

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